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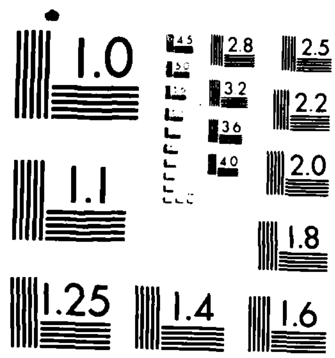
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FOREIGN TECHNOLOGY DIVISION

A PULSED MAGNETOHYDRODYNAMIC GENERATOR WITH A SUPERCONDUCTING MAGNETIC SYSTEM

by

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EDITED TRANSLATION

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А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
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К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
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М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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A PULSED MAGNETOHYDRODYNAMIC GENERATOR WITH A SUPERCONDUCTING MAGNETIC SYSTEM

USSR Academy of Sciences Member V. A. Kirillin, Correspondent Member A. Ye. Sheyndlin, E. I. Asinovskiy, V. V. Sychev, V. B. Zenkevich, A. M. Maksimov and V. A. Al'tov

An urgent need for creating independent sources of electric power capable of generating a power of tens or hundreds of megawatts in a few milliseconds has now emerged ([1]). A pulsed MHD generator, in which the conversion of mechanical energy of explosion products into electrical energy is accomplished, can serve as such a power source. There are published reports on testing of such MHD generators with ordinary magnetic systems ([2]). It seemed advisable to study the operation of a pulsed generator with a superconductive magnetic system in the overall plan of research on the creation of magnetohydrodynamic generators.

The creation of a pulsed MHD generator with a superconductive magnetic system would make it possible to improve substantially the operational indicators of the installation and to ensure its continuous operation, regardless of the presence of additional power sources for feeding the magnet. The problem of creating an optimum generator and a magnetic system with the maximum acceptable field intensity was not raised in the first stage. The purpose of the work was to investigate the set of questions which arise in the joint use of a pulsed MHD generator and a superconductive magnetic system.

The possibility of effective utilization of a superconductive magnetic system in combination with a pulsed MHD generator needs experimental testing. The question of the behavior of the magnetic system under conditions of strong interaction of the magnetic field with the plasma flow is of the greatest interest in this connection. In passage of the plasma piston in the duct of such a generator, components of the magnetic system undergo a mechanical shock. This shock is absorbed partially by the outer metallic shells of the cryostat. Nevertheless, since the specific electrical resistance of the wall material of the container containing liquid helium is significantly lower than that of the material of the outer shells, the characteristic damping time of eddy currents in the walls of the helium tank is relatively great, and the shock is transmitted to a considerable extent to the internal volume of the cryostat and, consequently, to the winding of the magnetic system. In addition, the passage of the plasma, which is equivalent in certain respects to the injection of a diamagnetic piston into the working volume of the magnetic system, leads to a current surge in the short-circuited superconducting windings. As a result of the screening effect of the metallic shells of the cryostat, the current pulse is small in size; however, we know that the energy dissipation involved with such rapid current changes, like the dissipation involved with mechanical shocks, can lead to the emergence of a normal phase nucleus in the superconducting winding. The problem is complicated by the fact that it is advisable to avoid so-called "full stabilization" of the magnetic system, which is achieved by injection of a large amount of a normal metal (copper or aluminum) into the composition of the conducting strand of the magnet winding, in relatively small superconducting magnets. A large average current density in the winding is normally achieved in unstabilized windings due to some decrease in the current density strictly in the superconducting material. With the appearance of a normal zone nucleus in an unstabilized superconducting winding, an uncontrolled transition process begins, leading to the release

all the energy delivered in the magnetic field in the form of heat.

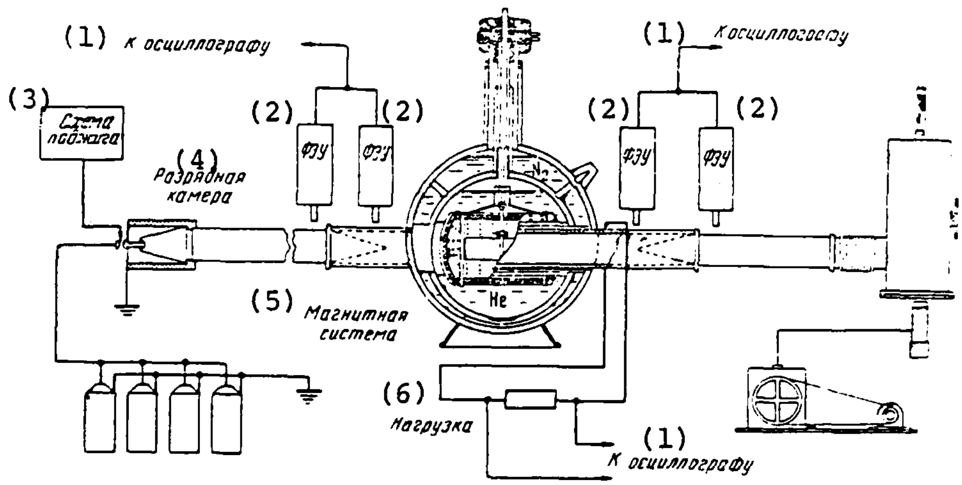

Fig. 1. Diagram of pulsed MHD generator with a superconducting magnetic system.
Key: (1) to oscillograph; (2) FEU [photomultiplier]; (3) ignition system; (4) discharge chamber; (5) magnetic system; (6) load.

A schematic diagram of the installation on which the experiments were performed is shown in Fig. 1.

The duct of an MHD generator with an independent magnetic system was tested on an electrical discharge shock tube with a conical discharge chamber ([3]). A discharge was created in the chamber by means of a battery of six capacitors of the IM5-150 type. The maximum energy stored by the battery reached approximately 11 kJ. The inner diameter of the shock tube amounted to 50 mm, and the length was 3.5 m. The vacuum system provided a vacuum of less than 10^{-5} mm Hg.

An MHD generator duct of a rectangular shape of 52x15x450 mm was produced from organic glass. The transition from a rectangular duct cross section to the round cross section of the tube was

effected by means of special sections. The generator was equipped with solid electrodes of copper foil with a width of 15 mm and a length of 165 mm. The distance between the generator duct and the discharge chamber was 2.5 m.

As indicated above, one of the main elements of the installation was the superconducting magnetic system. The winding of the magnetic system was constructed in the form of two identical sections placed symmetrically on both sides of the duct, creating a magnetic field transverse to the direction of movement of the plasma.

Each section was made up of 1570 turns and was wound with a single piece of seven-strand superconducting cable. The cable included a central stabilizing copper core with a diameter of 0.27 mm and six superconducting strands of the same diameter of a three-component alloy of Nb-Zr-Ti of the 65BT type. After twisting, the strands making up the cable were impregnated with indium of high purity and insulated with lavsan (Soviet equivalent of Dacron).* The calculated inductance of an individual section was 0.33 H. The mutual inductance of the sections is 0.078 H.

A system of superconducting shunts provided the possibility of disengaging the power source after the nominal current value has been achieved in the winding and operating in a "frozen current" mode. The winding of the magnetic system was placed in a cryostat whose design made it possible to use the magnetic system in an assembly with the duct of an MHD generator. The cryostat (Fig. 1) is made up of four copper spheres with diameters

*The superconducting cable based on the three-component alloy 65BT was developed jointly by the Central Scientific Research Institute of Ferrous Metallurgy, the VNII [All-Union Scientific Research Institute] of the cable industry and the AN SSSR [USSR Academy of Sciences] Institute of High Temperatures.

of 270, 310, 370 and 400 mm, a duct with an intermediate screen and a cryostat cover, to which the terminals of current and measurement wires are attached. The inner sphere serves as the chamber for liquid helium, in which the superconducting winding is placed. The cavity between the second and third spheres is filled with liquid nitrogen. The rest of the space is evacuated. The sphere surfaces facing the vacuum are carefully polished for reducing heat delivery by radiation. The duct in the cryostat bounding the working space at room temperature is made of a rectangular copper tube and has dimensions of 35x70x400 mm. The intermediate screen, with dimensions of 45x90x370 mm, is also made of copper; it is soldered into the nitrogen chamber and is cooled by heat conduction. The rectangular duct passing through the helium bath has dimensions of 60x110x270 mm. The winding of the magnetic system is attached to the rectangular copper tube which forms this duct. The current supplies leading into the bath with liquid helium were designed in such a way that they can be removed from the cryostat after the system is switched to the "frozen current" mode. This substantially reduced the losses of liquid helium. The consumption of liquid helium did not exceed 50 cm^3/h, which made it possible to use the magnetic system for several days after the initial filling with helium.

A so-called "training effect" characteristic of most unstabilized magnetic systems was observed in excitation of the magnetic system. This effect consists of an increase in the maximum magnetic field value after the winding is transferred into a normal state several times by exceeding of the critical current. In the magnetic system in question, the first transition of the winding into a normal state occurred at a field intensity in the working zone of the order of 12 kOe. The next transition was observed at a field intensity of about 14 kOe. Then the field intensity could be increased to a value somewhat greater than 15 kOe. An average current density along the winding of $1.1 \cdot 10^4$ A/cm^2 and a magnetomotive force of $1.7 \cdot 10^5$ At corresponded

to this field intensity level. The distribution of the magnetic induction along the duct axis is shown in Fig. 2.

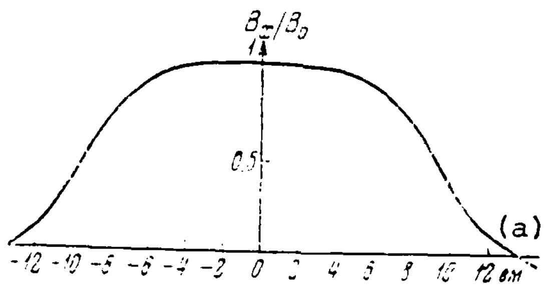

Fig. 2. Distribution of magnetic induction along the duct axis.
Key: (a) vM.

The experiment performed consisted of the following. After establishment of the working mode of the magnetic system, the shock tube was evacuated, after which it was filled with argon to a pressure of 0.5 mm Hg. At the moment of discharging of the capacitor battery, a dense plasma piston was created in the conical discharge chamber, forming a shock wave in front of itself in movement along the tube ([4]). The speed of propagation of the shock wave and of the gas discharge plasma was measured with three pairs of photomultipliers; one pair measured the flow rate of the plasma at a distance of 1 m from the inlet to the duct, the second pair measured the flow rate at the inlet to the duct, and the third measured the flow rate at the outlet from the duct. A set of resistances from 0.1 to 300 Ω was used as the duct load. All the signals were recorded with an S1-33 five-beam oscillograph.

The speed of the shock wave in the duct in the mode investigated reached approximately 5 km/s. The electrical conductivity of the plasma cluster amounted to several $\Omega^{-1}cm^{-1}$. Thus there

was a possibility of investigating the behavior of a superconducting magnetic system with sufficiently strong interaction of the magnetic field of the system with the plasma flow (the interaction parameter $\sigma B^2 l/\rho u \sim 1$). According to preliminary estimates, the elements of the magnetic system underwent a shock with a force of the order of 10 kG in the power off-take.

The value of the peak power of the generator amounted to from 10 to 100 kW, depending on the load. The duration of a voltage pulse on the load varied from 450 μs in an idling mode to 150 μs with a load of 0.1 Ω. This apparently attests to braking of the plasma flow with an increase in the current flowing through the plasma. This is also confirmed by measurements of the speed of the plasma at the inlet to and the outlet from the duct.

About 100 starts were performed in the process of the experiment, which lasted 12 hours. During this time, the magnetic system was disconnected from power sources, and the liquid helium supply in the cryostat was not replenished. No change was observed in the magnetic field intensity. The results of the experiments attest to the theoretical possibility of creating a pulsed MHD generator with an independent superconducting magnetic system.

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21 August 1967

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